Hf Broadband Time/Frequency Spreading

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LONG-TERM GOAL

The long-term goal is to develop a broadband time/frequency spread model which can be used in simulation to predict the performance of new signals and signal processing algorithms in shallow ocean environments where time and frequency (T/F) spread are often significant. This capability is required for sonar signal processing optimization and wideband signal and processor design.

OBJECTIVES

The scientific objectives are to measure T/F spread directly along with relevant environmental parameters (primarily wind speed, temperature and salinity profile, and bottom properties) at several shallow ocean regions, and from those measurements develop an empirical, environment-driven T/F spread model. This a model will be a correction to range-dependent ray tracing predictions made using validated boundary scattering and reflection models.

APPROACH

T/F spread over a one-way path in a shallow ocean channel may be measured by transmitting a high-resolution signal and recording the received signal at a hydrophone spatially separated from the transmitter. The received signals are matched filtered (MF) using replicas which have been generated by compressing or expanding the transmitted signal, an approach referred to as *wideband processing*. The MF output is the instantaneous spreading function (SF) convolved with the signal ambiguity function (AF). The AF depends only on the transmitted signal and the processing waveform, and the object is to extract the SF from the MF output. While deconvolution is the straightforward approach to extracting the SF from the MF output, deconvolution often performs poorly because of sensitivity to small values in the AF.

Our approach has been to decompose the MF output into the sum of basis functions convolved with the AF. If the time resolution of the MF output is sufficient to resolve individual paths, weighted phase delays are suitable basis functions. Otherwise, a radial basis function such as the two-dimensional Gaussians is a suitable basis function. In either event, a sum of suitably scaled or weighted, time delayed and/or frequency shifted basis functions is taken as the SF estimate.

In the ocean, the spreading function is a random quantity that can change appreciably with time and position. In practice one cannot ever predict the instantaneous SF. Therefore, we focus on understanding the statistics of the spreading process. An empirical, environment-driven model will

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be developed from the dependence of the SF statistics upon geometric and environmental parameters,

Christopher J. Link of Penn State's Acoustics Graduate Program developed the transmit signals, recorded the received signals, and processed the acoustic data shown in this report. ARL/PSU engineers and technicians directly supporting the data collection are Mark Barnoff, John Fleck, John Keller, and Michele Keller. German nationals who supported the at-sea experiment are Udo Kaiser and Kai Cordruwisch of WTD 71, Eckernförde; Bernd Nützel and Rudy Jacobsen of FWG, Kiel; and the officers and crew of the WTD 71 research vessels MzBk Kalkgrund and MzBm Helmsand.

WORK COMPLETED

Two at-sea T/F spread measurements have been conducted under a Shallow Water Acoustics for Torpedoes Project Agreement, which is part of a US-GE Memorandum of Understanding. In addition to ONR, Mr. Tim Douglas of NAVSEA PEO-USW sponsored the measurements.

During November-December 1996, a spreading function measurement was carried out in the Baltic Sea, in 45 m of water, at a site approximately midway between the southern tip of Sweden and the island of Rügens. The transmit signal consisted of a pair of 27-chip Costas codes which provided about 2.5 Hz frequency resolution, time resolution from 0.2 to 2.5 ms, and -15 dB sidelobe levels. We obtained approximately 200 pings each of signals with roughly 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4 km path lengths; 10, 20, 40 and 80 kHz center frequencies; and 2, 4, and 10 kHz bandwidths. Due to dropouts in the recordings, only the lowest resolution (2 kHz bandwidth, 2.5 ms time resolution) signals are useable. Results from this trial have been published.

A second spreading function measurement was conducted during April-May 1998 in the North Sea, in 32 m of water, at a site approximately 20 miles northwest of the island of Helgoland. This time a 50 ms binary phase shift keyed (BPSK) transmit signal was used, providing low sidelobes and about 20 Hz frequency resolution. Using a 250 msec repetition rate, between 56 and 80 pulses were recorded using each of three center frequencies (25 kHz, 50 kHz, and 90 kHz) and four bandwidths (1.25 kHz, 2.5 kHz, 5 kHz, and 10 kHz). The projector-to-receiver separation was varied from 665 m and 4100 m in approximately 500 m steps.

All of the North Sea data have been MF processed. MF decomposition routines have been developed in Matlab using a complex exponential as a basis function. T/F spread has been estimated for the 10 kHz bandwidth data. Preliminary results were presented at the ASA meeting in June 1998 in Seattle. Further results are shown below. A comprehensive report is being prepared.

RESULTS

Figure 1 shows the measurement geometry used in the North Sea experiment. The acoustic propagation measurement system (APMS) operates in a band up to 10 kHz wide using a selectable center frequency between 15 kHz and 95 kHz. For this measurement, projectors and hydrophones were suspended from German research vessels. The projector depth was 15 m, and hydrophones were located at depths of 8 m, 13 m, 18 m, and 23 m.

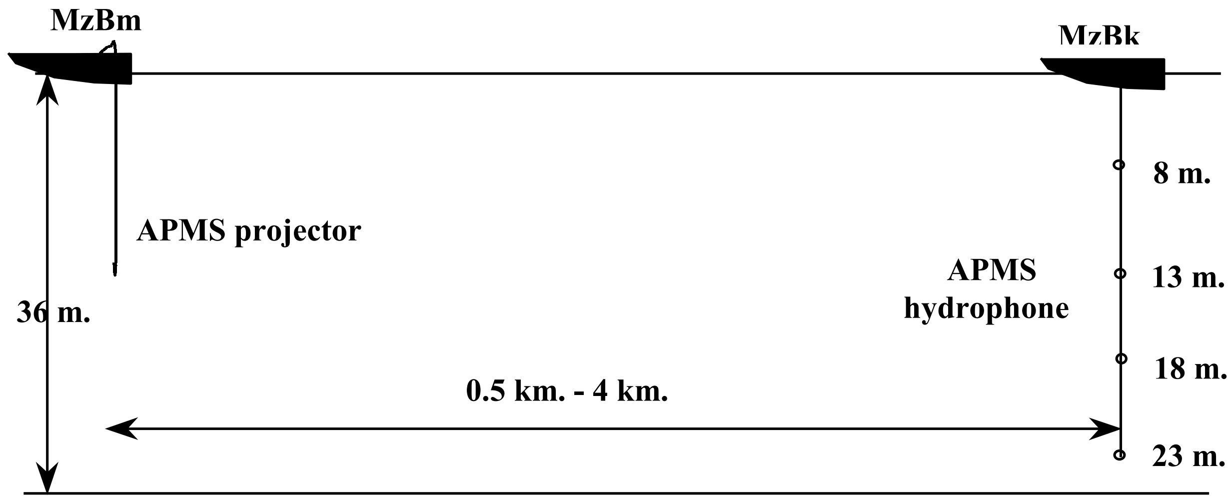

Figure 1. Experiment geometry used in the April-May 1998 time/frequency spread measurement in the North Sea using the acoustic propagation measurement system (APMS). MzBm and MzBk are medium and small German research vessels, respectively.

Figure 2 shows the time/frequency spread decomposition of a single pulse from the North Sea experiment. Projector-hydrophone range in Figure 2 is 665 m. Hydrophone depth is 18 m. The signal is a 50ms, 10 kHz bandwidth BPSK centered at 50 kHz. In each panel, the vertical axis is scale (=1+ 2*v/c) and spans about 150 Hz. The top panel shows matched filter output. The middle panel shows the 3-arrival spreading function estimate convolved with the ambiguity function. Estimation error is shown in the bottom panel. The MF estimate contains ~95% of volume in the MF output.

Figure 3 compares MF output measured in the North Sea (shown in red) with a prediction (shown in blue) obtained by convolving the signal AF with a predicted spreading function. Projector-hydrophone range is 3150 m; other parameters are the same as in Figure 2. Range-dependent ray tracing was used to predict the spreading function. Although range and depth were varied slightly to optimize the match, the need to further improve the fidelity of the MF output predictions is clear.

IMPACT/APPLICATION

When acoustic signals propagate through a shallow ocean region, the T/F distribution of energy at the *receiver* is shifted and extended (or spread out) relative to that of the *transmitted* signal. The time shift is due to propagation time. The principal causes of time spread are multipath (or micropath) and reflections from multiple scatterers. Relative movement between the transmitter, receiver and the scatterers leads to frequency shift. Multiple scatterers with different velocities cause the frequency spread wherein the spectrum of the received signal is wider than that of the transmitted signal. It is well known in the signal processing community that T/F spread can severely degrade processing performance.

The entire undersea weapons community is moving toward increased system bandwidth in order to improve signal to interference ratio (SIR), classification performance, and countermeasure resistance. However, the coherence of the propagation channel (and the target echo) across the frequency band, referred to as *frequency coherence,* must be known in order to optimally use increased system bandwidth. Ziomek (USNPGS) has derived the Fourier relationship between the mean square SF and the frequency-time correlation function, mainly that *spread* in *time* and *frequency* are inversely proportional to *coherence* across *frequency* and *time*, respectively.

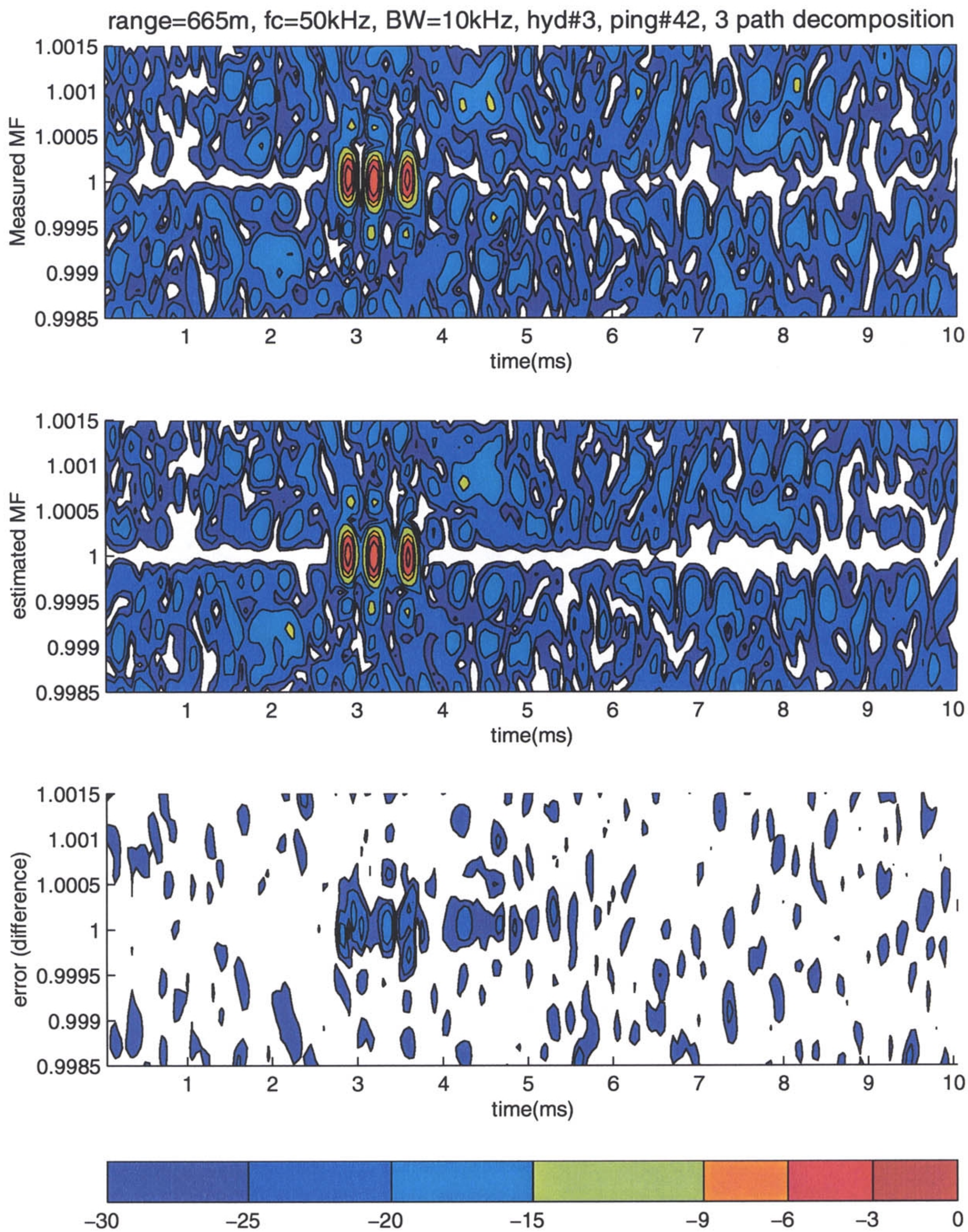

Figure 2. Time/frequency spread decomposition of North Sea experiment data. Proj-hydrophone range: 665 m. Proj, hydrophone depths: 15 m, 18 m. Signal: 50ms, 10 kHz bandwidth BPSK centered at 50 kHz. Matched filter output (top); spreading function convolved with ambiguity function (middle); estimation error (bottom).

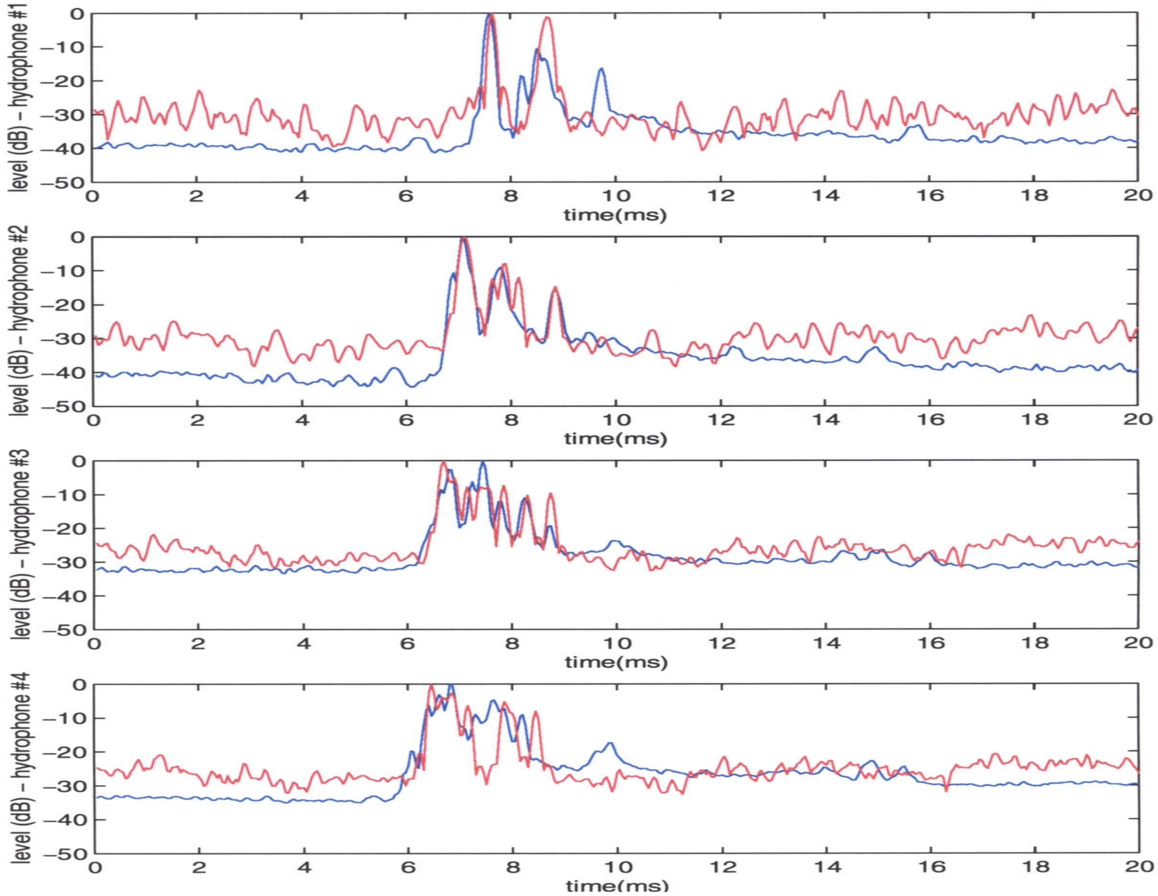

Figure 3. MF output measured in the North Sea (red) and predicted using a model-generated spreading function (blue). . Proj-hydrophone range: 3150 m. Hydrophone depths (top to bottom): 8m, 13m, 18m and 23m. Signal: 50ms, 10 kHz bandwidth BPSK centered at 50 kHz.

TRANSITIONS

The T/F spreading model will be used to optimize and test wideband signal processing concepts. Sibul (ARL/PSU) has formulated an Estimator-Correlator (EC) receiver structure that incorporates mean square SF estimates to optimize signal processing for shallow water and broadband signals. The T/F spreading model will be used to study EC sensitivity to T/F spread in the ONR 6.2 G&C program. Frequency coherence estimated from time spread data will be used in signal and signal processing design in the ONR 6.2 G&C program.

RELATED PROJECTS

- David Farmer (IOS/BC): High Frequency Propagation Studies in the Coastal Environment
- W.S. Hodgkiss (MPL/SIO): Fluctuations in High Frequency Acoustic Propagation
- Jules S. Jaffe (MPL/SIO): High Frequency Acoustic Propagation Studies
- Frank Symons el. al.: Broadband underwater weapons guidance and control projects

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